Eco-Friendly Pavement Solutions: Performance and Thermal Study of Steel Slag waste Modified Asphalt Mixes

Srivathsa H U[1], Chandini M S[2], Madhushree C[2], Manu K C[3], Kishor Kumar S[2*], Tapaswi H V[2]

[1]*Assistant. Professor, Department of Civil Engineering, ATME College of Engineering, Mysuru, India*
[2]*Assistant. Professor, Department of Civil Engineering, Malnad College of Engineering, Hassan, India*
[3]*Associate. Professor, Department of Civil Engineering, Malnad College of Engineering, Hassan, India*
Email: Skk@Mcehassan.ac.in

Abstract: The analysis of the behavioral change of temperature on rigid pavement is a critical aspect of understanding the performance and durability of Bituminous concrete roadways. Temperature fluctuations significantly impact the rigid pavement, leading to distresses such as cracking, deformation, and reduced service life. This experimental study aims to analyse the temperature distribution in Bituminous Concrete pavement with varying percentage of steel slag and to develop strategies to mitigate potential issues. To achieve this objective, a representative section of rigid pavement was selected for testing. The pavement sample was constructed according to standard specifications, ensuring it accurately represents real-world conditions. The sample consisted of typical layers found in a rigid pavement structure, including the concrete slab, base, and sub base layers. The collected data was analyzed to understand the effects of temperature changes on the rigid pavement. Statistical analysis and visualization techniques were employed to identify patterns, trends, and correlations between temperature variations and the observed behavioral changes. The analysis provided insights into the susceptibility of rigid pavements to temperature-induced distress, such as thermal cracking and differential expansion.

Keywords: Rigid Pavement, Steel Slag, LM 35sensor, Arduino, Bituminous, Temperature variation.

1. Introduction

Road transport is one among the crucial area of country's economic activity [1], as it plays an vital role in transporting agricultural products [2]. Impact of roads even in developed regions significantly affect the economy [3]. US accounts 15 percent of the (GNP) Gross National Product and that of 84 percent on transportation. A good network in a country makes it as a competitive edge in goods movement more economically. Conversely, lack of facility becomes a barrier to Industry, agriculture, trade and many more which hinders country's development. Nevertheless, the contributions of transport to national development may be difficult to quantify in economic terms. Pavement is made of flexible material laid down on the subgrade soil whose primary function is to carry vehicular traffic [4] and distribute the load evenly on the subsequent sub layers till the raw earth. Any road shall provide proper skid resistance, riding quality, favourable light-reflecting characteristics, and low noise pollution. Pavement are of two kinds - Flexible and Rigid Pavement. Most recommended type of pavement especially in developing countries like India is Flexible Pavement and getting funds for constructing the same is also a challenging task nowadays. It is mainly composed of asphalt or bitumen material. It is made of different composition in various layers where each of the layer receives the loads from above layers and distribute the same to the lower layers. It includes Surface layer (layer consists of bitumen and is in direct contact with the vehicle and surrounding medium), Base course (consists of aggregates in compacted form and lie exactly below HMA), Sub-Base Course (comes under base course not necessarily needed) and Sub-

Grade Course (formed by natural deposits of soil which is compacted to desired level capable enough to withstand the stress developed from the above layers) [5] as indicated in Fig 1 [6]. Minimal changes in the volume and stable configuration even under the adverse climatic condition and prevailing ground water level is the prime criteria for any sub grade which can be accessed by CBR test and will be the basis for deciding the pavement thickness as per IRC guidelines. Most convenient type of material for constructing the flexible pavement is bitumen and its performance may also vary due to prevailing climatic conditions and to mention few; especially in summer, temperature rises up makes the bituminous material softer turn out to be a disaster and in case of winter, decreases in temperature will be noticed which makes the material brittle. As in case of rainy season, rain descents enter the pavement due to its porous structure which is more than enough to form pot holes on its surface or sometimes even remove the entire layer. Effect on bitumen is never the less even in hilly areas as it will be subjected to alternate freezing and thawing cycles creates greater pot holes and becomes the primary reason for the failure of the layer. Lot of researchers have conducted investigation in accessing the properties of bitumen and resistance to moisture can be achieved by modifying the layer by adding chemical adhesives [7].

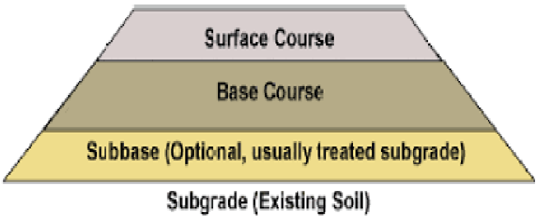

Fig. 1 Flexible Pavement Structure

Asphalt pavement is usually made of different layers with materials of good quality on the topmost where the vehicular and environmental forces act. Flexible pavements can also be referred as multi-layer system can be constructed by various layers viz Bituminous Concrete (BC), Bituminous Macadam (BM), Dense Bituminous Macadam (DBM), Wet Mix Macadam (WMM) and Granular Sub Base (GSB). BC primarily consists of binder and an aggregate mixed in a plant and transported to the site through a motorized machine laid over Sub Base Course in a single coat with thickness ranging from 50 to 100mm. In any Asphalt mix, filler becomes the vital ingredient have performed better against distresses caused. Aggregate fines passing through 75-micron sieve and occupies around 12 percent by mass in case of asphalt mixes. It should not contain any organic matters and possess a PI (Plasticity Index) less than 4 [8]. In case of Asphalt mix, Unlike others; filler plays a dual role. Coarser particles being an inert material fills the gap between larger particles and finer particles helps in improving the properties such as Consistency and Viscosity [9] . Fillers enhances the stability and optimizes the asphalt matrix due to improved material packing [10] behaviour. Choosing appropriate filler material and its relative mass in asphalt matrix influences the overall cost and pavement performance starting from its inception stage to end of its service life [11]. Keeping in view sustainability factor and higher inflation cost of pavement ingredients, lot of researchers are investigating the performance of pavement by replacing the conventional with alternative eco-friendly filler material. Works are being carried out in ascertaining the asphalt mix performance incorporating industrial processed waste such as bauxite residue [12], brick dust [13, 14], glass powder [8, 15] and Copper Slag [8]. Almost all industrial waste has positive influence on performance of asphalt matrix. Among all other industrial waste, Steel Stag is also one of the by-product obtained in steel manufacturing process. Waste Slag consists of CaO, FeO, SiO_2 and other properties are similar to Volcanic rocks [16]. Nowadays Steel Slag has wider applications in almost all Civil works. Waste Management for any type of industry or organization becomes a headache. Majority the waste goes for the landfill. But dumping the slag poses lot of health and environmental hazards as it contains toxic metals such as cadmium and led. Once these metals reach out to the soil and ground water, it becomes a threat for the entire ecosystem. Use of steel slag as a replacement for conventional aggregates gain its importance over recent years in terms of both environmental and economic benefits. Ensuring sustainability aspects, steek slag nowadays becomes a most vital alternate material in preparing BC mixes. Change in temperature has negative impact on flexible pavement. Crushed aggregates being the main component is non-sensitive to the temperature. Only the binder which holds the aggregates is more sensitive to temperature [17]. Temperature changes influence directly on stiffness of bitumen which modifies the stress level inside pavement layer due to which it impacts the pavement LCC (Life Cycle Cost) and thus demands regular maintenance of pavement which need to be investigated is of prime importance. Amount of maximum and minimum heat which is generated by any object is allowed to sense. This amount is measured by Temperature Sensors. This also detects the physical change and reproduce it analogue or digital output. There are varieties of Temperature Sensor depending upon the purpose to measure the different characteristics on its desired application. Temperature sensor is basically of two types; Contact and Non-Contact Temperature Temperature sensors have wider applications in Industrial processes, Environmental Monitoring, Home Automation, Medical Devices, Automative, Data Logging and Energy Management. LM 35 is one sort of Temperature Sensor used in the present work and shown in fig 2 [18].

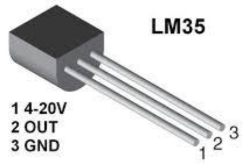

Fig 2: Temperature Sensor

2. Materials and Methods

2.1 Aggregates

Conventional Crushed aggregates of open graded sample and filler (Stone Dust) were collected from Amma Crushers, Hirakatti Village, Gundlupet Taluk, Chamarajanagar District of Karnataka, India. Aggregates samples were thoroughly sieved and washed in their respective sieves in order to remove the fine particles. Physical properties of crushed aggregates and filler were tested in the laboratory and results are presented in the Table 1

Table 1. Physical Properties of Aggregates

Material	Physical Properties	Test Specification	Obtained values
Crushed Aggregate	Specific Gravity	ASTM C127	2.78
	Water Absorption	ASTM C127	0.5
	Aggregate Crushing Value (%)	IS 2386 (Part IV)	26.69
	Aggregate Impact Value (%)	IS 2386 (Part IV)	13
	Los Angeles abrasion value (%)	IS 2386 (Part IV)	35.8
	Combined flakiness and elongation index (%)	IS 2386 (Part I)	18.46
Filler	Unit weight, dense (kg/m^3)	IS:2386(Part-3): 1963	1820
	Unit weight, loose (kg/m^3)	IS:2386(Part-3): 1963	1700
	Specific Gravity	IS:2386(Part-3): 1963	2.44
	Water Absorption (%)	IS:2386(Part-3): 1963	1.6

2.2 Bitumen

Bitumen a strong and viscous fluid basically containing hydrocarbons soluble in Tri-chloral ethane available in black colour. It is obtained by destructive distillation of crude oil. For the present work, bitumen of VG30 grade is procured from Krush Tar Industry Pvt. Ltd. Bengaluru, Karnataka, India. Physical properties of Bitumen was tested in the laboratory and results have been drawn and presented in the Table 2.

Table 2. Properties of Bitumen

Physical Properties	Obtained values
Absolute viscosity at 60ºC, (poise)	2683
Penetration at 25ºC, 100g, 5s, (0.1mm)	50
Softening Point, (Ring & Ball Apparatus) (ºC)	56
Ductility at 27°C (pull of 5 cm/ minute) (cm)	75
Specific gravity	0.9

2.3 Steel Slag

Steel slag basically obtained by BOF (Blast Oxygen Furnace) was procured from Subh Laabh Minerals, Hospet, Karnataka, India. In the present work, Steel Slag retained on 4.75 mm sieve is used as a replacement for Conventional aggregate in the range 0 to 15%. The physical properties of Steel slag are presented in Table 3.

Table 3. Properties of Steel Slag

Physical Properties	Obtained values
Specific Gravity	2.61
Loose Density (kg/cm^3)	1380
Compacted Density (kg/cm^3)	1530

2.4 Performance Analysis

One of the important climatic factor that controls the mechanical properties of the pavement is Temperature. One of the important response to solar radiation on road is, absorption and later its transmission. The varying properties of pavement materials and the process of the heat transfer from pavement is very essential to regulate asphalt pavement temperature. In addition to this, the best method to reduce the temperature from pavement is to harvest or transfer or convert to other form of energy. For transfer or conversion, minimum threshold temperature shall be observed on the pavement.

Aggregates and bitumen in relative amounts were heated up to 170^{0}C and 163^{0}C separately. Both the ingredients are thoroughly mixed and transferred to the mould arranged on compaction pedestal. The top surface of the specimen mix is tamped with 75 no. of blows using standard hammer. Same procedure is repeated for the specimen by keeping it in reverse manner. The entire specimen along with the mould was cooled down within few minutes. Specimen was removed from the mould with gentle push and it is brought down to room temperature overnight. A series of specimens were prepared by a similar method with varying quantities of Bitumen inclusive of Steel Slag (ranging from 0 to 15%) with an increment of 0.01% (3 specimens). Specimen was placed in a water bath having 60^{0}C for 0.5 hours before testing is carried out. Stability of the specimen was checked with Marshall Stability apparatus. After determining the stability of casted specimens, temperature analysis is performed by using LM 35 sensor. LM35 uses a solid-state technique to measure the temperature. The hardware assembly for measuring the temperature of the pavement is shown in fig 3 [19] and process is explained with a flowchart represented in fig 4.

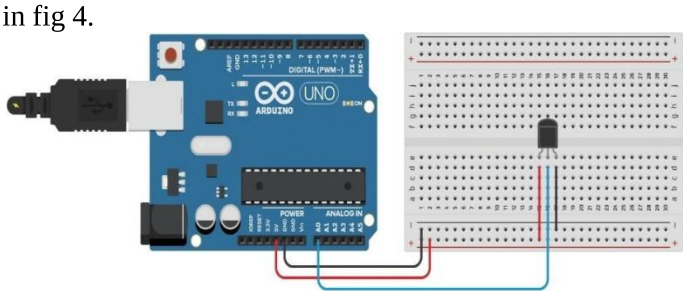

Fig 3. LM 35 Sensor with Arduino Uno Assembly.

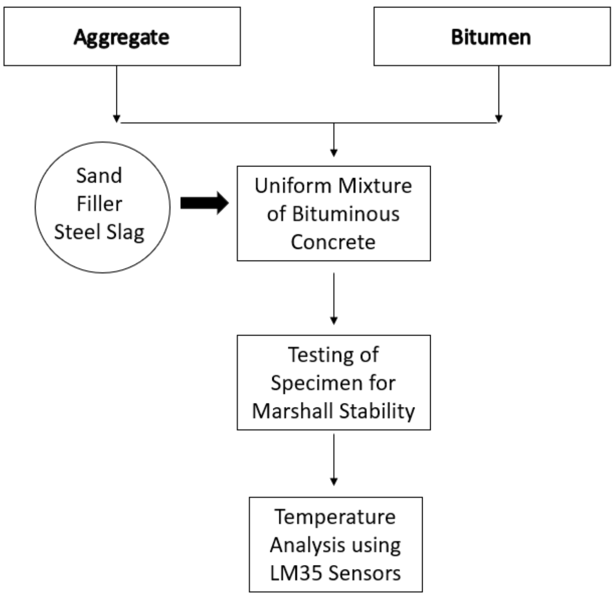

Fig 4. Flow chart of Performance Analysis of Bituminous Concrete mix

3 Results and Discussions

3.1 Marshall Stability Test

Stability analysis was carried out on the sample containing Steel Slag as a partial replacement for filler ranging from 0 to 15%. Stability values for different specimens is presented in the Table 4. Results showed that the Stability value increases as Steel Slag percentage increases up to 10% and thereafter the decrement in stability of specimen was observed for 15% replacement. It is due to the fact that as the percentage of steel slag increases, density of the specimen increases which improves the load carrying capacity.

Table 4. Marshall Stability tests results for varying percentages of Steel Slag

Particulars	Sample 1	Sample 2	Sample 3	Sample 4
Percentage of Steel Slag added	0	5	10	15
Weight of core in air	1572	1623	1691	1625
Weight of core in water	1056	1150	1191	1125
Weight of saturated surface dry core	1577	1650	1698	1627
Volume of the core	493cc	503cc	507cc	502cc
Density of core	3.03g/cc	3.30g/cc	3.33g/cc	3.23g/cc
Marshall stability	4.50kN	6.20kN	10.5kN	9.8kN
Flow value	1.86mm	1.92mm	2.07mm	2.02mm
Marshall quotient	2.30	3.80	5.07	4.85
Bitumen content	4.60%	5.30%	5.78%	5.43%

3.2 Temperature Analysis

The present study showcases the increased pattern of temperature distribution on the pavement for the varying percentage of steel slag replacement with respect to same meteorological condition. Temperature sensor were used to study the temperature pattern variation throughout the day, throughout the season. Sample data is shown in Table 5. The results demonstrate that min 2^o-3^oc and max 5^0-6^0c rise in temperature is trapped on the surface layer for 5% steel slag replacement. It is also observed that during raise in the morning (10.00am) the heat trapped is increased by 12-13^0C maximum (8-9^0c minimum) during mid noon(2.00pm). The temperature lately reduces by 3-4^0c by the evening(5.00pm). It clearly gives the understanding of temperature distribution follow almost regular pattern for 8hrs of the clear day. This trapped temperature on surface increases with increase in Steel Slag (15%) for wearing course of Bituminous Concrete. This is clearly tabulated in Table 5

Table 5. Temperature Analysis of Bituminous Concrete for varying percentage of Steel Slag

Days	Time	Conventional Temperature	5% Steel Slag	10% Steel Slag	15% Steel Slag
1	10.00 AM	30°C	33.92°C	34.92°C	36.58°C
	2.00 PM	37°C	42.36°C	47.23°C	55.5°C
	5.00 PM	32°C	38.52°C	43.14°C	52.6°C
2	10.00 AM	31°C	32.23°C	35.15°C	35.35°C
	2.00 PM	38°C	45.69°C	49.69°C	55.3°C
	5.00 PM	30°C	40.52°C	42.52°C	52.4°C
3	10.00 AM	29°C	33.81°C	34.81°C	35.25°C
	2.00 PM	34°C	39.92°C	42.76°C	46.3°C
	5.00 PM	31°C	34.55°C	39.58°C	41.4°C
4	10.00 AM	30°C	32.95°C	35.01°C	39.2°C
	2.00 PM	36°C	42.08°C	45.02°C	48.3°C
	5.00 PM	32°C	40.81°C	42.18°C	43.11°C

4. Conclusions

Steel Slag as by-product obtained as a waste in steel manufacturing industry can be effectively used as a replacement for Conventional Coarse Aggregates which helps in preserving the natural resources and eliminates the problems of disposal which requires lot of space for dumping it. The experimental work done in this research reveals the significant effectiveness of increase in performance of pavement properties including Marshall Stability, Flow value, Marshall quotient and Bitumen Content. The study demonstrates the increase in efficiency of the above said parameters with increase in steel slag for 5 &10%. But if the steel slag is further increased to 15%, it is observed the declining in values. The pavement also exhibits the increase in the trapped temperature for the varying percentage of steel slag. The pattern clearly indicates that increase in steel slag from 5 to 10 to 15%, the temperature distribution is increased by min 10-14^0c.

References

1. Dobariya, V.S., Experimental Investigation of Bituminous Concrete Mix Using Ceramic Waste and Rice Husk Ash as a Partial Replacement of Filler and Aggregate. 2018, Gujarat Technological University.
2. Tunde, A.M. and E. Adeniyi, Impact of road transport on agricultural development: a Nigerian example. Ethiopian Journal of Environmental Studies and Management, 2012. 5(3): p. 232-238.
3. Poumanyvong, P., S. Kaneko, and S. Dhakal, Impacts of urbanization on national transport and road energy use: Evidence from low, middle and high income countries. Energy policy, 2012. 46: p. 268-277.
4. Ahammed, M.A., Safe, quiet and durable pavement surfaces. 2009.
5. Jelušič, P., et al., Potential of Using Waste Materials in Flexible Pavement Structures Identified by Optimization Design Approach. Sustainability, 2023. 15(17): p. 13141.
6. Adhitya, B., et al. The utilization of plastics waste in flexible pavement hot rolled sheet and asphalt concrete wearing course with Marshall immersion and Cantabro test. in Journal of Physics: Conference Series. 2020. IOP Publishing.
7. Yi, J., G. Doré, and J.-P. Bilodeau, Monitoring and modeling the variations of structural behavior of a flexible pavement structure during freezing. Journal of Cold Regions Engineering, 2016. 30(4): p. 04016004.
8. Choudhary, J., B. Kumar, and A. Gupta, Performance evaluation of asphalt concrete mixes having copper industry waste as filler. Transportation Research Procedia, 2020. 48: p. 3656-3667.
9. Huang, B., X. Shu, and X. Chen, Effects of mineral fillers on hot-mix asphalt laboratory-measured properties. International Journal of Pavement Engineering, 2007. 8(1): p. 1-9.
10. Kandhal, P.S., C.Y. Lynn, and F. Parker, Characterization tests for mineral fillers related to performance of asphalt paving mixtures. Transportation research record, 1998. 1638(1): p. 101-110.
11. Cardone, F., et al., Asphalt mixture modification with a plastomeric compound containing recycled plastic: Laboratory and field investigation. Materials and Structures, 2022. 55(3): p. 109.
12. Choudhary, J., B. Kumar, and A. Gupta, Utilization of solid waste materials as alternative fillers in asphalt mixes: A review. Construction and building Materials, 2020. 234: p. 117271.
13. Arabani, M., S.A. Tahami, and M. Taghipoor, Laboratory investigation of hot mix asphalt containing waste materials. Road Materials and Pavement Design, 2017. 18(3): p. 713-729.
14. Kuity, A. and A. Das, Study on aggregate size distribution in asphalt mix using images obtained by different imaging techniques. Transportation Research Procedia, 2016. 17: p. 340-348.
15. Choudhary, J., B. Kumar, and A. Gupta, Application of waste materials as fillers in bituminous mixes. Waste management, 2018. 78: p. 417-425.
16. Kumar, H. and S. Varma, A review on utilization of steel slag in hot mix asphalt. International Journal of Pavement Research and Technology, 2021. 14: p. 232-242.
17. Nanaware, M.A., R. Rathod, and A. Deshmukh, Effect of Temperature Variation on Rigid Pavement by using Sensor.
18. Liu, C., et al. The application of soil temperature measurement by LM35 temperature sensors. in Proceedings of 2011 International Conference on Electronic & Mechanical Engineering and Information Technology. 2011. IEEE.
19. Oyebola, B. and O. Toluwani, LM35 Based digital room temperature meter: a simple demonstration. Equatorial Journal of Computational and Theoretical Science, 2017. 2(1).